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RESEARCH PAPER

Contribution of Small-Scale Agroforestry Systems to Carbon Pools and Fluxes: A Case Study from Middle Hills of Nepal

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Abstract In view of the heavy people's dependence (80 %) on various forms of land-based resources, carbon sequestration should not only be targeted in forests, but also on private land agroforestry. A survey was conducted in 2011 to investigate the gap in contribution of agroforestry carbon to the household economy in the middle hills region of Rasuwa district of Nepal. A total of 120 households were randomly selected and surveyed, of which eight were further examined for detailed tree carbon measurement. It is estimated that a total of 48.60 ton C per hectare has been stocked in agroforestry sites in the middle hills region. Assuming a carbon price of $US12/ton, the total potential income from carbon sequestration per household would amount to NPR 45,490/ha in 20 years of agroforestry if a payment scheme were introduced. The income from carbon sequestration is quite low compared with other agroforestry income. Policy implications are thus oriented towards farmers reaping multiple benefits from the existing international mechanisms by having negotiations based on contribution of all agroforestry components (farm trees, crops and animals) rather than limited to forest carbon stock. To benefit from these multiple functions of farms and forests, the policy framework to address the

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climate-related affects and risks (e.g., of landslides, burst of Himalayan lakes) should be broad enough to produce potential synergy between the negative effect of climate change and agroforestry income.

Keywords Trees on farms · Terrace risers · Carbon sequestration · REDD · Fodder production

Introduction

In subsistence hill agriculture, forests are an important factor to sustain production. Assorted species of trees and shrubs grown on farm land (agroforestry) are planted on terrace risers, edges of farmland and fallow land. Broadly defined, agroforestry (AF) is a land use that involves deliberate retention, introduction or mixture of trees or other woody perennials in crop and animal production fields to benefit from the resultant ecological interactions (including control of carbon emissions) and economic interactions (MacDicken and Vergara 1990). In Nepal, the whole farming system in which hill farmers are engaged can be considered as agroforestry (Garforth et al. 1999). Though modern AF with exotic fodder and grass species is still a relatively new practice in Nepal, hill farmers have been growing selected native tree species in association with field crops on their farmland to maintain land productivity and to provide for subsistence needs, including timber, fodder for livestock and fuelwood for cooking (Neupane et al. 2002). Assorted AF tree species grown on farmland have been an integral component of local economies because they are sources of animal feed and food and for cash earnings where farmers have access to market centres (Pandit 1994; FAO 1996; Neupane and Thapa 2001).

A typical agroforestry system allows synergistic interactions between woody and non-woody components to increase, sustain and diversify total land output (Swaminathan 1987; Nair and Nair 2003; Acharya 2011). Agroforestry not only supplements farmers' incomes, controls soil erosion, and maintains soil fertility, but also contributes to terrestrial carbon stocks. Apart from about one-third of Nepal's area as forest cover there is at least another 33 % of area under other land-use systems including pasture and agroforestry (ICIMOD 2010). Sustainably managed non-forest land has the potential to be a significant carbon sink. Thus there are great opportunities for increasing the contribution (decrease negative effect of climate change and increase farm income) of agroforestry to carbon sequestration.

In recognition of the carbon sequestration potential, this paper examines how to capture the benefits of carbon sequestration together with the benefits from other AF components. Agroforestry areas including agricultural cropping are important carbon reservoirs. Small changes in the size of these reservoirs can have major implications for CO_2 emissions and global climate change. Changes in land use and management practices greatly affect the stock of both above and below-ground carbon (CAST 1992; Lal et al. 1998; ICIMOD, 2010). The possibility of increased carbon storage in forests and agricultural vegetation is of great interest due to the fact that on an average, the vegetation and soil together contain approximately 2160 Pg C (Lal 1999), of which soil contains almost three times as much carbon as that 'above ground' (Batijes

1996). It is estimated that improved agricultural management practices could sequester worldwide between 400 and 800 Mt C/year (Leemans 1999). IPCC (2001) pointed to forest degradation as one of the most important land-use factors causing increased concentration of atmospheric CO_2. IPCC (2001) estimated that at the global level, 19 % of the carbon in the earth's biosphere is stored in plants, and 81 % in the soil (ICIMOD 2010). In all forests—tropical, temperate and boreal together—approximately 31 % of the carbon is stored in the biomass and 69 % in the soil (Karky and Skutsch 2009). Agroforestry is crucial in order to offset the loss of carbon due to deforestation (Neupane 2000; Pandit and Thapa 2004).

The Kyoto protocol paved the way to making efforts to include forest and soil carbon sequestration in the list of acceptable offsets (FCCC 1997). Subsequently, the United Nation Framework Convention on Climate Change (UNFCCC) conference held in Bali in 2007 focused more on the Reduced Emissions from Deforestation and Degradation (REDD) approach, which basically targeted the forestry sector in developing countries as a means to offset atmospheric carbon. Recently, the approach to consider carbon stocks beyond those limited to REDD and including farm agroforestry (REDD++) has emerged. To achieve benefits from farm agroforestry, Nepal needs to develop a mechanism that will provide incentives to people beyond forest management and including all sustainable land uses (Joshi et al. 2010). Nepal has 39 % of the land designated as forest, but less than 25 % real forest cover (FAO 2010). Therefore, a substantial area of land lies outside forests, including agroforestry on farm land. In this context, Joshi et al. (2010) argued that Nepal should include agriculture and other land-use change beyond pure forestry in its carbon negotiation strategy.

From the perspective of climate change and the global carbon cycle, agroforestry practices are attractive for two reasons: they directly store carbon in the tree component, and they potentially slow deforestation by reducing the need to clear forest land for agriculture (Pandit and Thapa 2004). Approximately 1.2 billion people, comprising 20 % of the world's population, depend directly on agroforestry products and services in rural and urban areas of developing countries (Nair and Nair 2003). But few studies have been carried out to calculate the amount of carbon stock in various land uses including in privately-owned agroforestry. The average carbon storage by agroforestry practices has been estimated as 9, 21, 50, and 63 Mg C per ha in semiarid, sub-humid, humid and temperate regions, respectively (Unruh et al. 1993). For smallholder agroforestry plantings in the tropics, potential annual carbon sequestration rates range from 1.5 to 3.5 t C/ha (Nair and Nair 2003). The annual average carbon sequestration rate in above and below-ground biomass of bamboo plantations in the western hills of Nepal were calculated as 1.66 t/ha and 0.08t/ha respectively (Ghatri-Chhetri, 2008).

Compared with forestry, there is only 23 % of the land under farming in Nepal, where approximately 66 % of the people are involved (Pandit and Thapa 2004; Upadhayay et al. 2005). Outside forest areas, farmers have been practicing various forms of agroforestry in Nepal, for which the carbon stock has not been assessed (Dhungana et al. 2007). Agroforestry is considered to encompass more broadly the larger landscape beyond individual farms, where private farmland, common access forest and grazing land, farm animals, water resources as well as household

members, all interact. KC (2011) estimated that CO_2 emissions from AF systems in Nepal were 0.15 % of the total global carbon sequestered through AF, which is considered to be a huge amount relative to the country's size. However, as argued by Joshi et al. (2010), with the increasing food demand in recent years, the area under cultivation is likely to increase, implying that net emissions are on the rise with the increasing use of high-yield varieties, chemical fertilizers and pesticides.

Given the multiple demands of Nepalese farmers (for food, fodder, leaf litter, timber and firewood) on a day-to-day basis, there is clear need to assess AF options and their potential for providing environmental benefits through carbon sequestration with livelihood incentives for the farmers. The state of the art linking AF to carbon pools and fluxes needs to be established in order to judge its multiple benefits including climate change mitigation. In subsistence agriculture on hill slopes, there exists a complementary relationship among trees, crops and livestock, where trees and crops provide fodder and litter as bedding material for livestock and in turn benefit from draft power and manure provided by animals (Neupane et al. 2002). This has been further justified from the fact that the average income of a family in the year 2007 from sale of livestock and livestock products (milk, meat and ghee) was NPR 25,416, which turned out to be almost 26 % of total household income, while the income was substantially lower (Rs. 6,465) for farmers having no agroforestry species planted on their land (Pandit 2008). This study further revealed that sale of agroforestry products including fruit, vegetables, grass, fodder and fuelwood returned nearly the same level of income as animal husbandry. Farmers with agroforestry have obtained more than three times the income of farmers without agroforestry. This income could be increased further by payment for environmental services (i.e., from agroforestry carbon sequestration), which has not yet been provided.

In the context of increased population pressure, deforestation and subsistence needs, this paper examines the contribution of agroforestry to carbon pools and fluxes in Nepal with particular reference to a study conducted by the Nepal Agroforestry Foundation (NAF), an NGO in the middle hills area of Rasuwa District, in the central development region of Nepal. The specific objectives of this paper are to review the contribution of agroforestry to carbon pools and fluxes in Nepal, and to present a case study demonstrating the contribution of agroforestry to carbon pools and fluxes.

Research Method

Both primary and secondary data were collected. The latter included reviews and assessments of the contribution of agroforestry to carbon pools and fluxes, made from reports and records of various government and non-government offices and organizations. Beside the forest policy documents, relevant scientific literature was reviewed in detail.

A case study was conducted in Dhaibung Village Development Committee (VDC) area of Rasuwa District of Nepal. This VDC is one of the six NAF's working VDCs (the others being Bhorle, Laharepauwa, Ramche, Dhunche and Syaphru) of the total 19 VDCs of Rasuwa district. VDC is the lowest strata of the governance structure, which is divided into nine wards, each consisting of one or more villages and

Fig. 1 Map of Nepal showing study site

settlements or communities, depending on population size. In mountainous and hill districts, wards are normally spread over relatively large areas that include village settlements or communities having few households. In these VDC areas, NAF has introduced exotic fodder trees and grasses including ipil ipil (*Leucaena leucocephala* and *L. diversifolia*), Calliandra (*Calliandra calothyrsus*), bhatmase (*Flemingia congesta*), NB 21 (Pennisetum sp.) and stylo (*Stylosanthes guianensis*) during the last two decades. Rasuwa District is located at latitude of 28°10′0 N and longitude of 85°19′60 E and is one of the least-developed mountainous districts in Central Nepal (Fig. 1). Dhaibung VDC lies in the southern-facing mid-hills region of the district, 50 km north of the national capital Kathmandu. Most of Rasuwa extends from the mid-hills to alpine areas (7,246 masl). Field visits were made by principal investigators and researchers to the study VDC, and tree measurements were taken from eight sample plots of eight farmers (four plots each elevation) out of 120 farming households surveyed for socio-economic information, as primary data.

A large area of the district is occupied by Langtang National Park, which has an area of 1,710 km^2. The main occupation of the inhabitants of the southern mid-hills area is agriculture. The population has a low level of literacy (40 %) and low socio-economic status. In northern parts of the district, people are mainly dependent on livestock raising and forest-based farming, including cultivation of medicinal herbs. In the mid-hills areas of the district, farmers grow maize, millet, potatoes, rice, wheat and barley. Most of the land is under terrace cultivation, with a relatively small area of leveled terraces. The study area lies on both sides of the Pashang Lhamu road linking Kathmandu to district headquarters of the Tibet autonomous region of China at Dhunche and to Kerung.

A household survey was conducted in Dhaibung VDC area, this area being selected as representative of middle hills region of Rasuwa District. The study area was selected considering the criteria including representation of both upper and lower elevation conditions, heterogeneous population, and high incidence of agroforestry

tree species on farmland. Two wards of Dhaibung VDC area were selected purposively, to analyze the socio-economic status of farmers within two elevation ranges, and compare their living standard and the amount of carbon in agroforesty tree species planted on their farmland. Sixty households—approximately 20 % of households—were randomly selected in each of Ward 6 (upper village) and Ward 4 (lower village). Sub-samples of four households from the 60 sampled households in each Ward were drawn randomly for biomass measurement that constituted the major data source. Two forestry graduates from Kathmandu Forestry College (KAFCOL) were hired by NAF for both socio-economic and AF inventory data collection over March to May of 2011. The data collection was supervised and monitored by the principal investigators.

The agroforestry inventory was undertaken to measure the number of herbs, shrubs and trees in specific units of land. For example for trees 25 × 20 m plots were used, for shrubs 10 × 5 m plots within selected tree plots, and for herbs 2 × 2 m plots within shrub plots, measured as nested plots. The numbers of trees, shrubs and herbs within plots were counted, and for trees the height and diameter at breast height were recorded. The inventory was conducted using a GPS, D-tape, 30 m simple tape, Relascope, Silva compass and Sunto clinometer. All inventory data collected were processed and tabulated using Microsoft Excel. The total carbon stock from branches, foliage, root, shrub and leaf litter was calculated using the following biometric equation and form factor (developed by GON, 2011):

$$\text{Basal area (BA)} = \pi \mathrm{d}^2/4$$

$$\text{Growing stock (GS/ha)} = \text{BA} \times \text{ht} * 0.5 \text{ (following Subedi et al. 2010)}$$

where d = diameter and h = height. Form factor = ff (GON, 2011). Here (1) Branch volume (BV/ha) = stem GS/ha × 0.341, (2) Foliage volume (FV/ha) = stem GS/ha × 0.067, (3) Root volume (RV/ha) = stem GS/ha × 0.27, (4) Shrub volume (SV/ha) = stem GS/ha × 0.057, (5) Leaf litter volume (LLV/ha) = stem GS/ha × 0.136. Total volume (m^3/ha) = BV + FV + RV + SV + LLV, Total biomass/ha = total volume × 0.72, Total carbon/ha = total biomass × 0.47, Annual Increment (AI) = total carbon × 2/100.

Results and Discussion

Traditionally, farmers in the study sites are managing trees by themselves on various types of private land. Tree plantating and management activity on private land was increased mainly after promulgation of the *National Parks and Conservation Act 1973,* which prevented local people from collecting forest products from the conservation area. In one form or another, hill farmers have long been practicing agroforestry to meet fodder and fuelwood requirements as well as to maintain land productivity. Farmers reported that in recent years these practices have become inadequate to meet the fodder requirements and replenish soil nutrients to increase food production.

It was observed that most agroforestry species are naturally grown on the edges of terraces and farm boundaries along with upland crops and on the walls of gullies and barren land called *kharbari,* where some kinds of thatch grasses grow naturally. The improved fodder trees and grasses are also planted on terrace edges and risers, and on fallow land, in close spacing by maintaining 1–2 m tree height. NAF recommends keeping the tree height low to minimize the adverse effects on crop yields.

In the study area, the rural population derives a substantial part of their daily supplies from AF species, including raw material to make bamboo baskets and mats from *Arundinaria intermedia* (nigalo), and fruit from *Myrica esculenta* (kafal), *Terminalia* and *Emblica* species. *Ficus semicordata* (raikhaniyo), *Arundinaria intermedia*, *Saurauja nepalensis* (gogan), *Brasiopsis hainla* (chuletro), *Ficus nemoralis* (dudhilo), *Myrica esculenta* (kaphal) and *Prunus cerasoides* (Pyainyu) are the commonly grown AF species in the upper village. Similarly *Ficus lacor* (kabro), *Litsea monopetala* (kutmiro), *Artocarpus lakucha* (baddar), *Bauhinia purpurea* (tanki), *Emblica officinalis* (amala), *Shorea robusta* (sal) and *Schima wallichii* (chilaune) are typical species grown at lower elevation. Most of the species listed above have multiple products, including fodder, fuelwood, timber and NTFPs. However, their main purpose is for animal fodder. Three exotic fodder tree species introduced by NAF in the study area—*Leucaena leucocephala*, *L. diversifolia* and *Flemingia congesta*—are mostly planted on terrace edges to enrich the soil for the crops grown on the terraces. An average of 247 fodder trees, 23 fruit trees and 16 fuelwood and timber trees per farm were observed in the study area (Table 1).

Growing Stock Assessment

The number of agroforestry trees grown on the eight selected farms ranged from 400 to 860 and the growing stock (GS) ranged from 34 to 404 m^3/ha (Table 2). The lower belt village was found to have a higher growing stock (259 m^3/ha) than the upper village (64.6 m^3) due to its warmer and more humid climate.

The total volume calculated using form factors for the various sources of carbon production indicate that the lower belt agroforestry system produces a much higher volume (230 m^3) than the upper village agroforestry system (56.5 m^3) (Table 3). The difference is mainly associated with variation in intensity and species composition of agoroforestry as well as micro-climatic conditions between the two elevations. The lower belt is relatively moist while the upper belt remains mostly dry with low temperature for most of the year. There is relatively high nutrient loss from soil erosion in the upper belt because of the steep land and sloping terraces.

Table 1 Number of agroforestry trees grown on farm

Village	Number of fodder trees	Number of fruit trees	Number of fuelwood and timber trees	Total
Upper village	189	10	13	212
Lower village	305	36	18	359
Total	247	23	16	285

Table 2 Growing stock in the eight inventoried farms (m^3/ha)

Village	Number of trees (/ha)	Diameter (cm)	Basal area ($\pi d^2/4$)	Mean tree height (m)	Growing stock (m^3/ha)
Upper village					
Farmer 1	520	0.22	0.0380	8.0000	79.0275
Farmer 2	680	0.19	0.0283	9.2500	89.1246
Farmer 3	460	0.15	0.0177	8.4200	34.2052
Farmer 4	400	0.2	0.0314	9.1000	57.1480
Sub-total	515	0.19	0.0288	8.6925	64.5727
Lower village					
Farmer 5	740	0.24	0.0452	9.5000	158.9342
Farmer 6	760	0.28	0.0615	10.0000	233.8672
Farmer 7	800	0.31	0.0754	8.7000	262.5260
Farmer 8	860	0.33	0.0855	11.0000	404.3511
Sub-total	790	0.29	0.0669	9.8000	259.0522
Total or average	653	0.24	0.0479	9.2463	161.8124

However, the upper belt has the advantage of being suitable for cultivation of high value and low volume medicinal and aromatic plants. The overall volume of production was 143 m^3/ha in 2011 (Table 3).

Biomass and Carbon Sequestration

Various factors affect production of tree biomass and corresponding carbon production, particularly climate, vegetation type, planting density and harvesting (cutting) as well as management system. Total carbon stock depends upon the total biomass production. The total carbon stock in the lower village (78.08 ton/ha) was higher than that in the upper village (19.12 ton/ha). Based on a hypothetical calculation of the value of carbon at the rate of USD 12/ton, the upper village would receive a total of NPR[1] 17,896 from 19 ton C per ha, while the lower belt farming household would receive more than four times as high income (NPR 73,008) from carbon trading (Table 4). The average total carbon stock of eight farms is 48.60 t/ha, which accounts for the potential carbon value of NPR 45,490/ha. Average annual increment of carbon in the study area is 0.97 t/ha/year, which is equivalent to NPR 908 ha/year at the $12/ton price.

[1] USD 1 = NPR 78 at the time of survey.

Table 3 Total stock volume from branch, foliage, shrub, root and leaf litter (m^3/ha)

Village	Stem volume	Foliage volume	Shrub volume	Root volume	Leaf litter volume	Total volume
Upper village						
Farmer 1	26.95	5.29	4.50	21.34	10.75	68.83
Farmer 2	30.39	5.97	5.08	24.06	12.12	77.63
Farmer 3	11.66	2.29	1.95	9.24	4.65	29.79
Farmer 4	19.49	3.83	3.26	15.43	7.77	49.78
Sub-total	22.12	4.35	3.68	17.52	8.82	56.49
Lower village						
Farmer 5	54.20	10.65	9.06	42.91	21.62	138.43
Farmer 6	79.75	15.67	13.33	63.14	31.81	203.70
Farmer 7	89.52	17.59	14.96	70.88	35.70	228.66
Farmer 8	137.88	27.09	23.05	109.17	54.99	352.19
Sub-total	90.34	17.75	14.77	71.53	36.03	230.41
Average total	56.23	11.05	9.22	44.52	22.43	143.45

Table 4 Total biomass and carbon production

Location	Total biomass (ton/ha)	Total carbon stock (ton/ha)	Annual increment (ton/ha/year)
Upper village			
Farmer 1	49.56	23.29	0.47
Farmer 2	55.89	26.27	0.53
Farmer 3	21.45	10.08	0.20
Farmer 4	35.84	16.84	0.34
Average upper village	40.69	19.12	0.38
Lower village			
Farmer 5	99.67	46.85	0.94
Farmer 6	146.66	68.93	1.38
Farmer 7	164.64	77.38	1.55
Farmer 8	253.58	119.18	2.38
Average, lower village	166.14	78.08	1.56
Average, eight farms	103.41	48.60	0.97

Table 5 Sources of cash earning per household

Source of cash income	Upper belt average income (NPR/year)	Lower average income (NPR/year)
Sale of farm crops (cereals)	1,500 (3)	6,230 (10)
Sale of livestock and livestock products	6,439 (12)	10,600 (18)
Sale of agroforestry products (NTFP/MAP)	6,500 (12)	3,605 (6)
Sale of cash crops (potatoes and vegetables)	1,294 (2)	1,100 (2)
Wage labour	7,935 (15)	8,200 (14)
Hotel and tourism business	6,072 (11)	6,500 (11)
Salary and pension	4,502 (8)	7,530 (12)
Remittance	15,600 (29)	13,000 (22)
Others (incl. fuelwood and fodder)	3,690 (7)	3,500 (6)
Total	53,532 (100)	60,265 (100)

Figure in parentheses are percentages of total income

Carbon Sequestered Through AF and Other AF Incomes

The rural landscape that encompasses the agrarian economy, fragile ecology and complex and differentiated society is changing rapidly with creation of new opportunities and challenges. Despite this rapidly changing environment, the rural economy is still based on subsistence agriculture. In such a context, the cash income derived from agroforestry products (mainly medicinal plants) in the upper belt and livestock income in lower belt will play a significant role in sustaining rural livelihoods. The income generated from agroforestry in the study area has opened up new opportunities for the hill farmers (Table 5). The differences in AF income (medicinal plants) is mainly because of climatic suitability to grow high-value medicinal plants in the upper elevation (Pandit and Thapa 2004). The greater income from livestock in the lower belt is attributed to greater fodder production that is used for feeding milk and meat producing animals. This income is additional to what AF contributes to carbon sequestration (0.97 t/ha/year). The carbon sequestered from AF is thus an integral component of the whole system outputs, which cannot be seen as a separate entity.

Of all sources of income, remittance has been the largest contributing source, contributing 29 and 22 % of the total household cash earnings in upper and lower zone respectively in 2011. This remittance is earned due to out-migration of rural youth, which consequently resulted in fallowing or abandonment of large tracks of fragile landscape in the study area. This land is utilized effectively through expansion of AF, which would contribute to both carbon sequestration and farm

income in the hill slopes of Nepal, and it is expected to reduce the trend of migration.

Conclusion and Policy Implications

Agroforestry systems in middle hills of Nepal contribute to hill farming communities for both increased financial returns and environmental integrity. The carbon contribution is complementary to the whole system. However, Nepal still needs to push forward in reaping significant benefits for farmers from existing international mechanisms by having negotiations with IPCC on the basis of such contribution.

In the past, the focus has been on forest carbon stocks from forestry plantation. This focus now needs to be extended to other systems including agroforestry that have multiple benefits. The management of agroforestry is crucial to increase resilience of the ecosystems and increase incomes of rural families. Management options purposed to enhance carbon sequestration include inter-sowing of grass and legume tree species, introduction of deep-rooted species, conservation tillage, and crop rotation of fast-growing fodder tree species, such as *L. leucocpphala* and *F. congesta.*

Nepal's heavy reliance on land-based agriculture makes it difficult to justify protection of any forest land solely for mitigating emissions. In the highly complex farming systems, both agriculture and forestry are important and cannot be viewed in isolation from each other. There is substantial scope for reducing carbon emissions from agriculture and yet increasing productivity because Nepal's farming practice is largely carbon-friendly and there are opportunities for further strengthening and enhancing carbon-rich farming by supporting many of the traditional farming practices. Nepalese farmers have been practicing agroforestry without any financial incentives for their contribution to carbon sequestration and will continue practicing this land use as long as they continue practicing agricultural systems comprising field crops, trees and livestock. Hence, traditional systems modified to diversify production while concomitantly achieving carbon capture promise to be the best option for the future.

In view of benefits received from other farm forestry income (fodder, fuelwood, timber and non-timber products) combined with carbon stock, Nepal should lobby for widening the scope of carbon financing beyond the current REDD (Reduced Emission for Deforestation and Forest Degradation) model. This study suggests that because many small farmers in the hills of Nepal interact with land in a variety of ways for multiple objectives, a simple distinction of forest or non-forest has little relevance. Instead of indulging in the trade-off between farms and forests, the REALU (Reducing Emissions from All Land Uses) framework may help produce synergy by integrating both forests and agriculture (ICIMOD, 2010). This may help agriculture-dependent communities to reap significant benefits and to play an active role in climate change mitigation.

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